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ALUMINUM ALLOY ROLLED SHEET FOR FORMING PROCESSES, AND MANUFACTURING METHOD THEREFOR

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(72) Inventor: Mamoru Matsuo
c/o Sky Aluminum K.K.
4-1 Muromachi, Nihonbashi, Chuo-ku, Tokyo

(72) Inventor: Toshiki Muramatsu
c/o Sky Aluminum K.K.
4-1 Muromachi, Nihonbashi, Chuo-ku, Tokyo

(72) Inventor: Toshio Komatsuhara
c/o Sky Aluminum K.K.
4-1 Muromachi, Nihonbashi, Chuo-ku, Tokyo

(72) Inventor: Kazuhiro Fukada
c/o Sky Aluminum K.K.
4-1 Muromachi, Nihonbashi, Chuo-ku, Tokyo

SPECIFICATION

1. **Title of the Invention**

ALUMINUM ALLOY ROLLED SHEET FOR FORMING PROCESSES AND MANUFACTURING METHOD THEREFOR

2. **Claims**

(1) An aluminum alloy rolled sheet for forming processes, which is characterized by the fact that [a] said sheet contains 2 to 6% (wt %) Mg, [b] said sheet further has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, with the remainder of said sheet consisting of Al and unavoidable impurities, and [c] the maximum size of intermetallic compounds contained in the matrix is 5 μm or smaller.

(2) An aluminum alloy rolled sheet for forming processes, which is characterized by the fact that [a] said sheet contains 2 to 6% Mg, [b] said sheet further has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, [c] said sheet further has one or more element contents selected from a set consisting of 0.05 to 2.0% Cu and 0.1 to 2.0% Zn, with the remainder of said sheet consisting of Al and unavoidable impurities, and [d] the maximum size of intermetallic compounds contained in the matrix is 5 μm or smaller.

(3) A method for manufacturing an aluminum alloy rolled sheet which is characterized by the fact that [a] a melt of an aluminum alloy [i] which contains 2 to 6% Mg, and [ii] which has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, with the remainder of said sheet consisting of Al and unavoidable impurities, is continuously cast into a sheet with a thickness of 3 to 15 mm, and is then subjected to cold rolling, [b] the sheet is then rapidly heated to a temperature in the range of 400 to 600°C at a temperature elevation rate of 1°C/sec or greater, and [c] the sheet is then cooled from this temperature at a cooling rate of 1°C/sec or greater.

(4) A method for manufacturing an aluminum alloy rolled sheet which is characterized by the fact that [a] a melt of an aluminum alloy [i] which contains 2 to 6% Mg, [ii] which has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, and [iii] which further has one or more element contents selected from a set consisting of 0.05 to 2.0% Cu and 0.1 to 2.0% Zn, with the remainder of said sheet consisting of Al and unavoidable impurities, is continuously cast into a sheet with a thickness of 3 to 15 mm, and is then subjected to cold rolling, [b] the sheet is then rapidly heated to a temperature in the range of 400 to 600°C at a temperature elevation rate of 1°C/sec or greater, and [c] the sheet is then cooled from this temperature at a cooling rate of 1°C/sec or greater.

3. Detailed Description of the Invention

Field of Industrial Utilization

The present invention relates to [a] an aluminum alloy rolled sheet which is used in molded and worked articles that require high strength and superior forming and working characteristics, especially elongation, stretch-forming characteristics and bending characteristics, such as automobile body sheets and air cleaners, and oil tanks, etc., and [b] a method for manufacturing the same.

Prior Art

Conventionally, cold-rolled sheet steel has been used as an automotive sheet material for the forming of automobile body sheets, etc. Recently, however, there has been an increased demand for the use of aluminum alloy rolled sheets in place of conventional cold-rolled sheet steel, for the purpose of reducing the weight of automobile bodies and improving fuel consumption.

In the past, aluminum alloy rolled sheets used in such applications have included Al-Mg type 5052 alloy O materials and 5182 alloy O materials, Al-Cu type

2036 alloy T4 treated materials, and Al-Mg-Si type 6009 alloy T4 treated materials and 6010 alloy T4 treated materials.

Problems to Be Solved by the Invention

Conventional aluminum alloy rolled sheets of the types described above are inferior to cold-rolled sheet steel in terms of forming characteristics, especially elongation, bending characteristics and stretch-forming characteristics.

Specifically, among the Al alloys described above, 5052 alloy O materials and 5182 alloy O materials, etc., are relatively satisfactory from the standpoint of forming characteristics; nevertheless, such materials have a somewhat low elongation, and are inadequate in terms of bending characteristics and stretch-forming characteristics. Furthermore, in the case of O materials consisting of Al-Mg type alloys such as 5052 alloys and 5182 alloys, Lueders' marks are generated during forming and working, thus leading to a danger of an unsatisfactory external appearance. Methods for preventing the generation of such Lueders' marks include a method in which a slight amount of work strain is applied by leveling, etc.; in this case, however, there is conversely a deterioration in the forming characteristics.

The present invention was devised in light of the above facts; the object of the present invention is to provide [a] an Al-Mg type aluminum alloy rolled sheet which has forming characteristics, especially elongation, bending characteristics and stretch-forming characteristics, superior to those of conventional Al-Mg type 5052 alloy O materials and 5182 alloy O materials, and which preferably shows no generation of Lueders' marks, and [b] a method for manufacturing the same.

Means Used to Solve the Abovementioned Problems

The present inventors conducted various experiments and investigations concerning methods for improving the forming characteristics, especially elongation, bending characteristics and stretch-forming characteristics, of Al-Mg type alloy rolled sheets. As a result of these investigations, the inventors discovered that maintaining

the maximum size of intermetallic compounds in the final rolled sheet at 5 μm or smaller is effective in improving the elongation, bending characteristics and stretch-forming characteristics of the sheet. Furthermore, the inventors discovered that first performing direct continuous casting of the alloy melt into a sheet with a sheet thickness of 3 to 15 mm in the casting stage of the alloy melt is an effective means of maintaining the maximum size of intermetallic compounds in the final rolled sheet at 5 μm or smaller as described above, and that the application of a high-temperature heat treatment using rapid heating and rapid cooling following the cold rolling process is also effective in improving the forming characteristics. These discoveries led to the perfection of the present invention.

In concrete terms, the aluminum alloy rolled sheet of the first invention of the present application is characterized by the fact that [a] said sheet contains 2 to 6% Mg, [b] said sheet further has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, with the remainder of said sheet consisting of Al and unavoidable impurities, and [c] the maximum size of intermetallic compounds contained in the matrix is 5 μm or smaller.

Furthermore, the aluminum alloy rolled sheet of the second invention of the present application is characterized by the fact that [a] said sheet contains 2 to 6% Mg, [b] said sheet further has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, [c] said sheet further has one or more element contents selected from a set consisting of 0.05 to 2.0% Cu and 0.1 to 2.0% Zn, with the remainder of said sheet consisting of Al and unavoidable impurities, and [d] the maximum size of intermetallic compounds contained in the matrix is 5 μm or smaller.

Moreover, the aluminum alloy rolled sheet manufacturing method of the third invention of the present application is characterized by the fact that [a] a melt of an aluminum alloy [i] which contains 2 to 6% Mg, and [ii] which has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, with the remainder of said sheet consisting of Al and unavoidable impurities, is continuously cast into a sheet with a thickness of 3 to

15 mm, and is then subjected to cold rolling, [b] the sheet is then rapidly heated to a temperature in the range of 400 to 600°C at a temperature elevation rate of 1°C/sec or greater, and [c] the sheet is then cooled from this temperature at a cooling rate of 1°C/sec or greater.

Furthermore, the aluminum alloy rolled sheet manufacturing method of the fourth invention of the present application is characterized by the fact that [a] a melt of an aluminum alloy [i] which contains 2 to 6% Mg, [ii] which has one or more element contents selected from a set consisting of 0.05 to 1.0% Mn, 0.03 to 0.3% Cr, 0.03 to 0.3% Zr and 0.03 to 0.3% V, and [iii] which further has one or more element contents selected from a set consisting of 0.05 to 2.0% Cu and 0.1 to 2.0% Zn, with the remainder of said sheet consisting of Al and unavoidable impurities, is continuously cast into a sheet with a thickness of 3 to 15 mm, and is then subjected to cold rolling, [b] the sheet is then rapidly heated to a temperature in the range of 400 to 600°C at a temperature elevation rate of 1°C/sec or greater, and [c] the sheet is then cooled from this temperature at a cooling rate of 1°C/sec or greater.

Effect

First, the reasons for setting the alloy compositions used in the present invention will be described.

Mg:

Mg is a basic alloy component in the aluminum alloys used in the present invention, and is an element which contributes to the strength and forming characteristics of the material. In cases where the Mg content is less than 2.0%, the strength is inadequate so that the alloy is unsuitable for use in automobile body sheets, etc.. On the other hand, if the Mg content exceeds 6.0%, casting becomes difficult. Accordingly, the Mg content was limited to a range of 2.0 to 6.0%.

Mn, Cr, Zr, V:

These elements are all effective in improving the strength and evening out the structure by reducing the size of recrystallized particles. In cases where the Mn

content is 0.05% or less, the Cr content is 0.03% or less or the Zr content is 0.03% or less, the abovementioned effects cannot be obtained. On the other hand, if the Mn content exceeds 1.0%, the forming characteristics deteriorate, and if the Cr, Zr or V content exceeds 0.3%, coarse intermetallic compounds are formed. Accordingly, the Mn content was limited to the range of 0.05 to 1.0%, and the Cr, Zr and V contents were respectively limited to the range of 0.03 to 0.3%. Furthermore, any of these elements may be added singly, or combinations of two or more of these elements may be added.

Cu, Zn:

These elements are effective in improving the strength of the alloy, and are also effective in preventing the generation of Lueders' marks. Accordingly, especially in the case of the second invention of the present application, one or both of these elements are added. In the method stipulated by the third invention of the present application, the generation of Lueders' marks can be prevented, and in particular, the generation of Lueders' marks can be effectively prevented even in cases where no Cu or Zn is added, if the heat treatment performed following cold rolling is performed at a high temperature of 450°C or higher. However, the generation of Lueders' marks can be prevented more surely and stably by the addition of Cu and/or Zn. Here, if the Cu content is less than 0.05% or the Zn content is less than 0.1%, the abovementioned effect cannot be obtained. On the other hand, if the Cu content or Zn content exceeds 2.0%, the corrosion resistance drops. Accordingly, in the second invention, the amount of Cu added is set at 0.05 to 2.0%, and the amount of Zn added is set at 0.1 to 2.0%. Furthermore, in the second invention, either Cu or Zn may be added singly, or both of these elements may be added together.

In addition to the abovementioned elements, ordinary aluminum alloys contain Fe and Si as unavoidable impurities. Fe and Si are not particularly important elements in the present invention; however, if the contents of these elements exceed 0.5%, the amount of crystal deposition increases so that the forming characteristics deteriorate. Accordingly, it is desirable that the contents of both of these elements be 0.5% or less.

Furthermore, in addition to the respective elements described above, Ti or both Ti and B may be added in order to reduce the size of recrystallized particles. However, in order to prevent the crystallization of initial particles of $TiAl_3$, it is desirable that the Ti content be set at 0.15% or less. Furthermore, in order to prevent the formation of TiB_2 particles, it is desirable that the B content be set at 0.01% or less.

In the aluminum alloy rolled sheets of the first and second inventions of the present application, it is important not only that the alloys have the abovementioned compositions, but also that the maximum size of intermetallic compounds at the rolled surfaces of the final rolled sheets be 5 μm or smaller. The forming characteristics, especially the bending characteristics, elongation and stretch-forming characteristics, can be improved by thus setting the maximum size of these intermetallic compounds at 5 μm or smaller. In cases where the maximum size of the abovementioned intermetallic compounds exceeds 5 μm, the abovementioned effects cannot be obtained. In order to reduce the size of the intermetallic compounds in the final rolled sheets in this way, it is desirable that the alloy be directly cast to a sheet thickness of 3 to 15 mm by continuous casting in the casting stage, and that the solidification rate be increased, as will be described later.

Next, the methods used to manufacture the abovementioned aluminum alloy rolled sheets, i. e., the third and fourth inventions of the present application, will be described.

In these manufacturing methods, it is important first of all that in the casting of an aluminum alloy melt of the composition described above, this alloy be continuously cast into a sheet with a sheet thickness of 3 to 15 mm. In regard to the concrete method used, it is desirable to use a method in which the alloy melt is continuously fed between a pair of rolls cooled from the inside, and these rolls are continuously rotated so that a sheet solidified to a sheet thickness of 3 to 15 mm is continuously drawn out. As a result of such direct continuous casting into a thin sheet, a high solidification rate can be obtained.

As was already described above, it is necessary that the solidification rate following casting be high in order to keep the maximum size of the intermetallic compounds at the rolled surface of the final rolled sheet at 5 μm or smaller. The present inventors have ascertained by experiment that a cooling rate of 1°C/sec or greater and an average dendrite arm spacing of 10 μm or less are necessary in the case of alloys of this type. Such conditions can be satisfied by direct continuous casting of the alloy into a sheet with a sheet thickness of 3 to 15 mm. Here, in cases where the cast sheet thickness is less than 3 mm, the casting itself is difficult; on the other hand, in cases where the sheet thickness exceeds 15 mm, it is difficult to maintain the average dendrite arm spacing at 10 μm or less, so that it becomes difficult to maintain the maximum size of intermetallic compounds in the final rolled sheet at 5 μm or smaller. Accordingly, the desired forming properties, especially sufficient elongation, bending characteristics and stretch-forming characteristics, cannot be obtained.

The sheet continuously cast as described above is subject (if necessary) to a homogenization treatment at 350 to 550°C, and is then cold-rolled to a specified thickness. The rolling ratio in this cold rolling may be determined in accordance with the thickness of the cast sheet and the thickness of the final product sheet; ordinarily, however, it is desirable that this ratio be set at approximately 20% or less.

Following the abovementioned cold rolling, the sheet is rapidly heated to a temperature in the range of 400 to 600°C at a temperature elevation rate of 1°C/sec or greater, and is then rapidly cooled from this temperature at a cooling rate of 1°C/sec or greater. By thus rapidly heating the sheet to a high temperature, and then rapidly cooling the sheet, it is possible to reduce the size of recrystallized particles, and to improve the forming characteristics, especially elongation and stretch-forming characteristics. Here, if the temperature elevation rate is less than 1°C/sec, good forming characteristics cannot be obtained; furthermore, if the heating temperature is less than 400°C, recrystallization remains incomplete, so that the forming characteristics deteriorate.

On the other hand, if the heating temperature exceeds 600°C, eutectic melting occurs and the crystal particles grow into coarse particles. Moreover, if the cooling rate is less than 1°C/sec, the forming characteristics, especially the elongation and stretch-forming characteristics, deteriorate.

Furthermore, it is desirable that the heating temperature used in this heat treatment be in the range of 400 to 600°C, and preferably in the range of 450 to 550°C. If the heating temperature is thus set in the range of 450 to 550°C, a great reduction in the size of the crystal grains and a great improvement in the elongation and stretch-forming characteristics can be achieved; furthermore, the generation of Lueders' marks can be surely and stably prevented. Furthermore, in the case of alloys containing added Cu or Zn, no generation of Lueders' marks is seen throughout the entire temperature range of 400 to 600°C; however, even in the case of alloys containing no Cu or Zn, a rolled sheet which is free of Lueders' marks can be obtained by performing the abovementioned heat treatment at a temperature of 450 to 550°C.

Embodiments

The alloys indicated by alloy Nos. 1 through 5 in Table 1 were continuously cast into sheets with a thickness of 6 mm by a continuous casting process in which the alloy melt was continuously fed between a pair of cooled rotating rolls. The continuously cast sheets thus obtained were cold-rolled to a thickness of 1 mm, and were then subjected to respective heat treatments as indicated by conditions A through H in Table 2. Furthermore, in Table 2, the continuous annealing was accomplished in each case by holding for 10 seconds, and batch annealing was accomplished by holding for 2 hours.

Furthermore, the alloys indicated by alloy Nos. 6 through 8 in Table 1 were cast into slabs with a thickness of 400 mm by means of a DC casting method used as a comparative method, and these slabs were subjected to a homogenization treatment for 10 hours at 500°C. Afterward, the slabs were hot-rolled at 450°C into hot-rolled sheets with a thickness of 6 mm. These hot-rolled sheets were then cold-rolled into

sheets with a thickness of 1 mm. Next, the cold-rolled sheets were subjected to respective heat treatments indicated by conditions I through L in Table 2.

Following the abovementioned heat treatments A through L, the maximum size of the intermetallic compounds at the rolled surfaces were investigated. The results obtained are shown in Table 2.

Furthermore, the mechanical strength (tensile strength, proof stress) of the respective sheets obtained following the aforementioned heat treatments A through L, as well as the elongation, Eriksen value, minimum bending radius and presence or absence of Lueders' marks, were also investigated. The results obtained are shown in Table 3.

Furthermore, in regard to the O and × marks assigned to the various conditions in the remarks column, cases where the respective condition is within the ranges stipulated by the present invention are indicated by O, and cases where these conditions are outside the ranges of the present invention are indicated by ×.

Table 1. Chemical compositions of test alloys (wt %).

Alloy No.	Cu	Si	Fe	Mn	Mg	Zn	Cr	Ti	Zr	V	Remarks
1	0.03	0.09	0.25	0.35	4.53	Tr	0.04	0.01	Tr	Tr	within range of invention
2	0.70	0.15	0.23	0.05	3.61	Tr	Tr	0.01	Tr	Tr	"
3	0.41	0.14	0.23	Tr	4.20	1.2	Tr	0.01	0.11	Tr	"
4	0.03	0.11	0.20	0.10	4.30	1.5	Tr	0.01	Tr	0.08	"
5	Tr	0.12	0.22	0.06	3.95	Tr	0.04	0.02	Tr	Tr	"
6	0.04	0.10	0.23	0.35	4.50	0.01	0.04	0.01	Tr	Tr	"
7	2.31	0.30	0.20	0.24	0.35	Tr	Tr	0.02	Tr	Tr	outside range of invention
8	0.29	0.86	0.20	0.24	0.85	Tr	Tr	0.02	Tr	Tr	"

Table 2

Conditions	Alloy No.	Heat treatment conditions				Max. size of intermetallic compds. in final sheet	Remarks		
		Temp.	Heating rate	Cooling rate	Heat treatment means		Alloy composition	Casting conditions	Heat treatment conditions
A	1	530°C	20°C/sec	50°C/sec	continuous casting	3.5 μm	O	O	O
B	1	420°C	"	"	"	3.2 μm	O	O	O
C	2	550°C	"	"	"	4.1 μm	O	O	O
D	3	530°C	"	"	"	2.9 μm	O	O	O
E	4	550°C	"	"	"	3.8 μm	O	O	O
F	5	535°C	"	"	"	3.2 μm	O	O	O
G	1	320°C	"	"	"	3.2 μm	O	O	O
H	1	350°C	$1x10^{-2}$°C/sec	$5x10^{-3}$°C/sec	batch casting	3.7 μm	O	O	X
I	6	530°C	20°C/sec	50°C/sec	continuous casting	9 μm	O	O	X
J	6	350°C	10^{-2}°C/sec	$5x10^{-2}$°C/sec	batch casting	9 μm	O	X	O
K	7	500°C	10°C/sec	>1000°C/sec (water-cooled)	continuous casting	10 μm	O	X	X
L	8	530°C	20°C/sec	>1000°C/sec (water-cooled)	"	11 μm	X	X	O

Note: O marks in the remarks column indicates conditions within the range of the present invention; × marks indicate conditions outside the range of the present invention (same for Table 3).

Table 3

Conditions	Alloy No.	Tensile strength (kg/mm^2)	Proof stress (kg/mm^2)	Elongation	Er value (mm)	Minimum bending radius (mm)	Lueders' marks	Remarks		
								Alloy composition	Casting conditions	Heat treatment conditions
A	1	29.1	13.5	34	10.1	0.1	absent	O	O	O
B	1	29.6	14.3	31	9.9	0.2	slightly present	O	O	O
C	2	31.7	17.3	33	10.2	0.1	absent	O	O	O
D	3	30.7	16.5	33	10.1	0.1	absent	O	O	O
E	4	28.9	13.1	34	10.2	0.1	absent	O	O	O
F	5	29.0	13.1	31	10.2	0.1	absent	O	O	O
G	1	29.3	14.3	28	9.5	0.4	present	O	O	X
H	1	29.3	14.4	25	9.2	0.7	present	O	O	X
I	5	29.2	13.9	31	9.6	0.5	absent	O	X	O
J	5	29.7	14.5	25	9.3	0.6	present	O	X	X
K	6	33.3	18.6	25	8.7	1.0	absent	X	X	O
L	7	31.3	16.0	26	8.9	1.0	absent	X	X	O

It is clear from Table 3 that in the case of alloys in the composition ranges stipulated by the present invention, rolled sheets which are superior in terms of strength and forming characteristics can be obtained by rapidly solidifying the alloys by means of continuous casting, cold-rolling the solidified alloys, and then subjecting the cold-rolled sheets to rapid heating and rapid cooling. Furthermore, in the case of alloys in the composition ranges stipulated by the present invention, the generation of Lueders' marks can be suppressed and the forming characteristics can be improved to some extent even in cases where DC casting is used, if the heat treatment conditions are set in the ranges stipulated by the present invention (conditions I). In such cases, however, the improvement is not as conspicuous as in the case of the manufacturing method of the present invention, in which the abovementioned casting conditions and heat treatment conditions are combined.

Merits of the Invention

The aluminum alloy rolled sheet for forming processes provided by the present invention is superior in terms of forming characteristics, especially elongation, bending characteristics and stretch-forming characteristics, compared to ordinary conventional Al-Mg type alloy O materials. Furthermore, this sheet has sufficient strength for use as an automobile body sheet, etc.; accordingly, this sheet is suitable for use in applications were superior forming characteristics and strength are required, as in automobile body sheets, etc. Furthermore, the aluminum alloy rolled sheet of the present invention shows little generation of Lueders' marks, and such Lueders' marks can be surely and stably prevented especially in cases where Cu or Zn is added, or in cases where the abovementioned heat treatment following cold rolling in the manufacturing process is performed at a temperature in the range of 450 to 550°C. Accordingly, the occurrence of an unsatisfactory external appearance due to the generation of Lueders' marks in the forming process can be prevented.

Furthermore, as was described above, the aluminum alloy rolled sheet of the present invention is optimally suitable for use as an automobile body sheet; however, it goes without saying that this sheet also shows superior performance in formed articles and other applications in which strength is required, e. g., automotive parts

such as wheels, oil tanks and air cleaners, etc., various types of caps and blinds, aluminum cans, household articles, measuring instrument covers, and chassis of electrical equipment, etc.

Applicant: Sky Aluminum K.K.

Agent: Takehisa Toyoda, Patent Attorney (and one other)